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An attempt to catch a falling plate on a vibrating surface without contact

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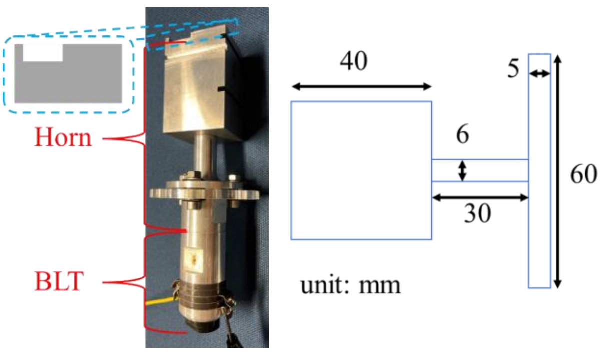
1. Introduction

When a planar object is placed on a non-flat vibrating surface that vibrates like a piston, near-field acoustic levitation of the planar object occurs, and further increasing the vibration amplitude causes, the planar object to jump due to a sudden increase in acoustic radiation force from the vibrating surface.[1)] Furthermore, by providing a depression on the vibration surface at an off-center position, it is possible to cause rotation and jumping in one direction simultaneously.[2)] The reverse of this operation requires the planar object to be held by the vibrating surface without contact, but this has not been studied so far. However, it is very difficult to catch a free-falling planar object on the vibrating surface in a non-contact manner because the object assumes various postures due to air resistance without contact. Therefore, to simplify the problem, we consider holding a one-degree-of-freedom rotating plate to be received by a vibrating surface in a non-contact manner.

The purpose of this study is to identify and clarify the problem of catching a rotating plate in a non-contact, near-field acoustic levitation state, and to model and automate the process.

2. Experiment method

Figs. 1(a) and **1(b)** show the transducer and the plate with a T-shaped axis used in this experiment. The transducer used in the experiment was a bolt-clamped Langevin transducer (BLT) with a square horn with a 3 mm deep recess located 2.5 mm from the edge of the vibrating surface, with a resonance frequency of approximately 40.7 kHz. Since it is not easy to stabilize the posture of a falling plate, a T-shaped rotation fulcrum is provided on the plate. The plate is made of acrylic, is 0.5 mm thick, and weighs 1.304 g. As shown in **Fig. 2**, the plate can be rotated perpendicular to the surface by a T-shaped part through the inner ring of the ball bearing housed in the bearing holder, serving as a rotation axis. Here, the inner ring is not moved but is used as a sliding bearing for the T-shaped shaft. The behavior of the plate was observed when it was dropped onto the vibrating surface, and the vibration amplitude was increased, which was considered through an analysis of the acoustic radiation force. In addition, the plate was recorded with a video camera to evaluate whether it could be captured by near-field acoustic levitation. The rotation angle θ is defined in **Fig. 2**. A high-speed camera with a frame rate of 3200 FPS was used. The light was shone from behind, and the presence or absence of light leakage between the plate and the vibrating surface was used to determine whether the plate was in contact with the vibrating surface.



(a) Overall transducer (b) Plate with T-axis
Fig. 1 Vibration source and plate used for the experiment.

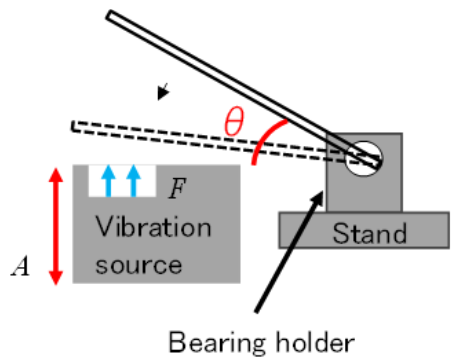


Fig. 2 Rotating plate support method and arrangement of vibrating surface.

3. Experiment and Analysis

Fig. 3 shows the measured plate motion angles versus vibration amplitudes. When the plate was on the vibrating surface, it was confirmed that the plate did not move (retained) at rotation angles of approximately 1°, 6°, 10°, 17°, 23°, and 29°. This phenomenon reduces the kinetic energy of the falling

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plate and simplifies the problem of receiving the plate. In this study, the state of the receiving plate is also considered as the initial position. **Fig. 4** shows the analysis results of the rotational torque due to acoustic radiation force at each rotation angle when the vibration amplitude was 10.1 μm. **Fig. 4** also shows the results of the sound pressure field analysis at the peak of the rotational torque. The sudden increase in rotational torque was due to the generation of standing waves. Comparing **Fig. 3** and **Fig. 4**, the mechanism of the rotation angle at which the plate was held was as follows: First, the plate moved up at an angle where the rotational torque became larger due to the effect of standing waves. As the plate moved up, this effect gradually decreased. Eventually, the rotational torque due to the acoustic radiation force became smaller than the rotational torque due to weight, causing it to move down. Here, Tf is the rotational torque due to acoustic radiation force, and Tm is the rotational torque due to gravity. This process was repeated within a small range and thus appeared to be held in place. Furthermore, as the amplitude increased, the rotational torque also increased, so the angle that could be held also increased.

Fig. 5 shows an example of successfully catching a plate by near-field acoustic levitation. **Fig. 6** shows the change in vibration amplitude at that time. Sequence control was used here in which, the amplitude was increased to jump and hold the plate, then the amplitude was decreased to fall the plate, and just before it hit the vibrating surface, the amplitude was momentarily increased to catch it using near-field acoustic levitation. However, even if the vibration amplitude was changed, as shown in **Fig.6**, it was not always possible to reliably catch the plate without contact.

4. Conclusion

The T-axis was attached so that the plate could rotate, and when the vibrator was driven, the state of the plate on the vibration plane was observed. It was found that the plate stopped rotating and falling at rotation angles of approximately 1°, 6°, 10°, 17°, 23°, and 29°. The mechanism of this phenomenon can be explained in terms of the balance of rotational torque. It was also found that it was possible to receive the plate using near-field acoustic levitation if the vibration amplitude was controlled to increase just before contact. In the future, it will be necessary to model the rotational motion of the plate and develop an amplitude control model for automatic control.

Acknowledgment
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References

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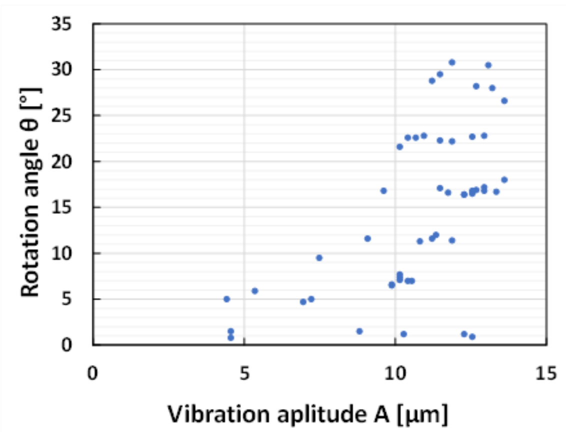

Fig. 3 Vibration amplitude A vs Rotation angle θ.

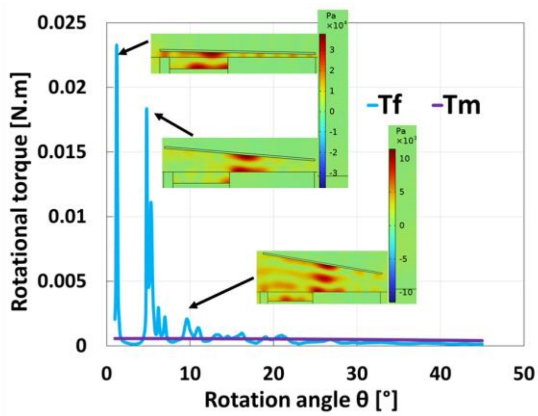

Fig. 4 Rotation angle θ vs Rotational torque.

Fig. 5 A state where plate was caught without contact on vibrating surface.

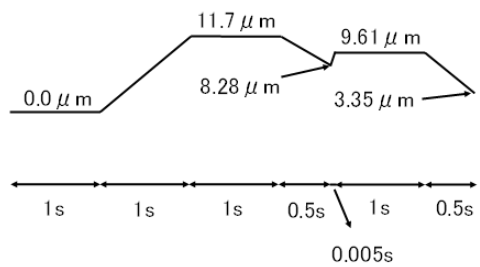

Fig. 6 Example of change over time of vibration amplitude for a non-contact catch on vibrating surface.